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LONG-TERM TRACKING OF ARCTIC ICEBERGS.(U)
APR 79 R Q ROBE, D C MAIER

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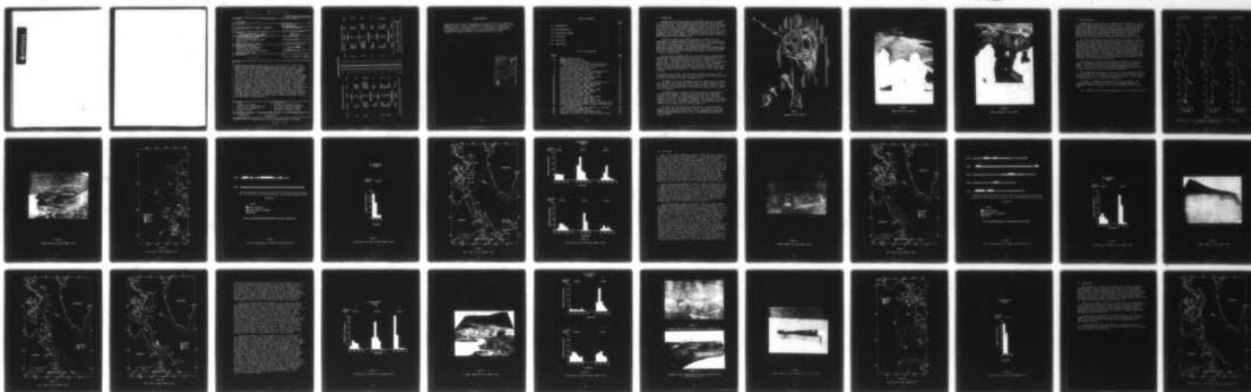
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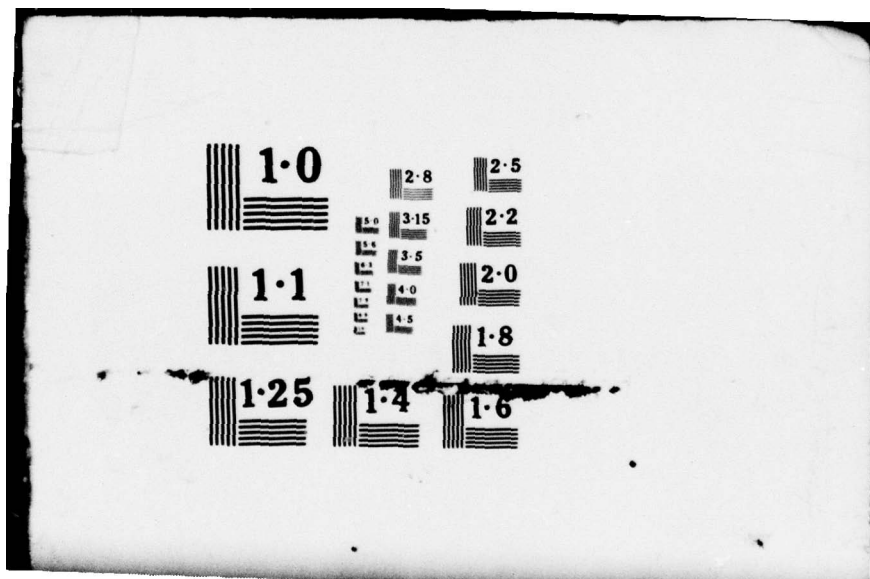
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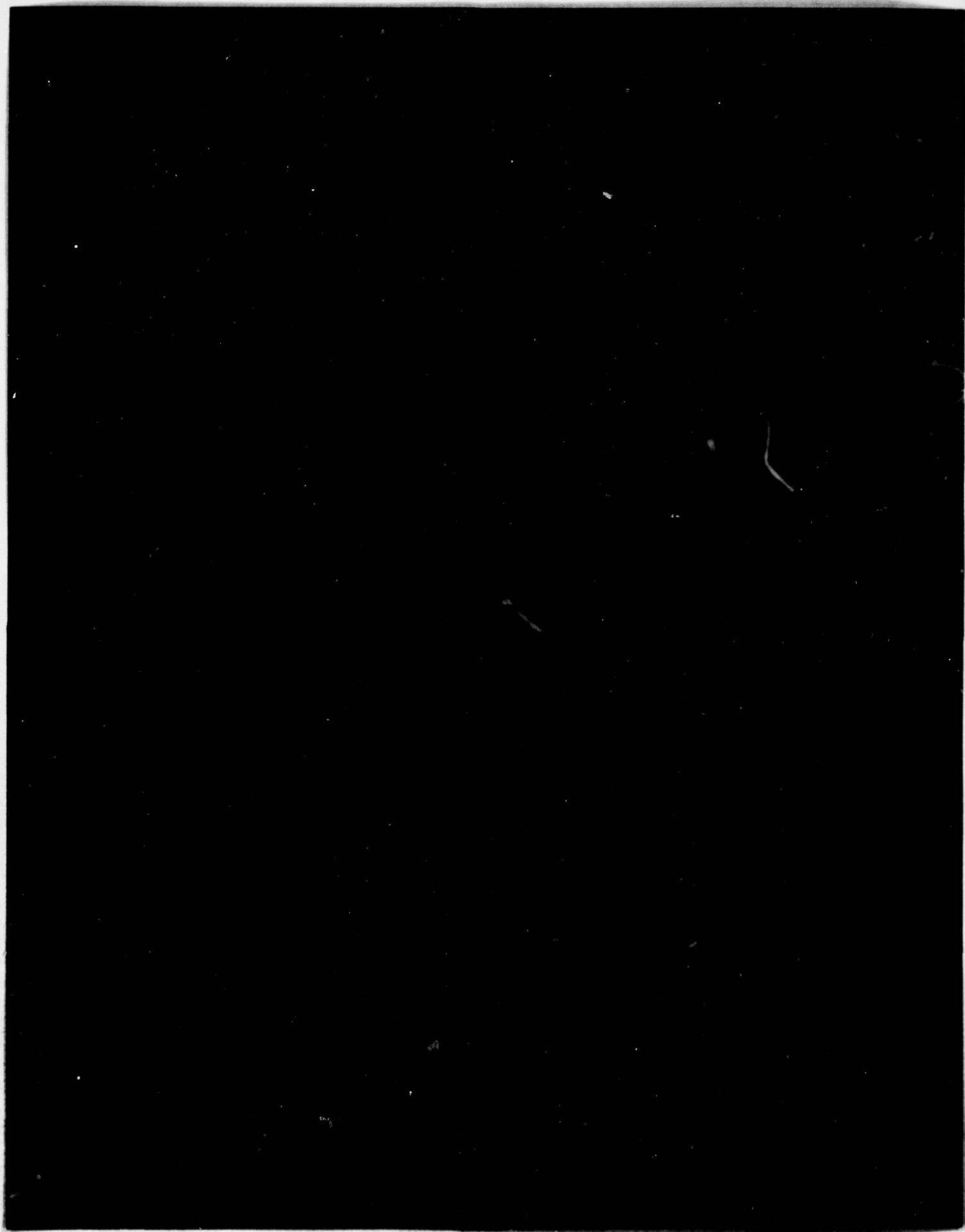


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16. Abstract Seven Greenland icebergs were tracked, two in 1977 and five in 1978, using ADRAMS (Air-Deployable Random Access Measurement System) ice buoys. The ice buoys transmit a signal to the NIMBUS-6 satellite which is used in computing the buoy's position. Observation periods ranged from 138 days to 202 days. The tracking of two icebergs began near Disko Island, Greenland, and the tracking of the other five began on the Baffin Island side of Baffin Bay near Davis Straits. The icebergs initially located near Disko Island did not appear to be influenced by any well-defined current system, the drift track of each was erratic and the drift speeds generally less than 0.20 m/s. The icebergs initially located along the coast of Baffin Island followed the prevailing currents southward. These icebergs drifted at speeds as high as 0.8 m/s with model speeds generally falling between 0.10 m/s and 0.20 m/s. Groundings occurred frequently occupying 40 percent of the observed time. Data processing methods, accuracy of the ice buoy system, and a detailed analysis of each iceberg's drift is presented. It was estimated using the drift data obtained, that approximately 190 days are needed for an average size iceberg to travel the 1100 nautical miles from Cape Dyer, Baffin Island, to the outer limits of the Grand Banks of Newfoundland.		
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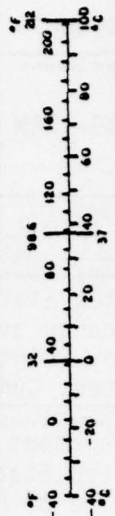
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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
LENGTH				
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
AREA				
sq in	square inches	6.5	square centimeters	cm ²
sq ft	square feet	0.09	square meters	m ²
sq yd	square yards	0.8	square meters	m ²
sq mi	square miles	2.6	square kilometers	km ²
	acres	0.4	hectares	ha
MASS (weight)				
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
VOLUME				
fl oz	fluid ounces	30	milliliters	ml
cup	cups	0.24	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
cu ft	cubic feet	0.03	cubic meters	m ³
cu yd	cubic yards	0.76	cubic meters	m ³
TEMPERATURE (exact)				
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Symbol	When You Know	Multiply by	To Find	Symbol
LENGTH				
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
km	kilometers	1.1	miles	mi
		0.6	miles	mi
AREA				
cm ²	square centimeters	0.16	square inches	in ²
m ²	square meters	1.2	square yards	yd ²
ha	hectares	0.4	square miles	mi ²
km ²	square kilometers	2.6	square miles	mi ²
	hectares (10,000 m ²)		acres	
MASS (weight)				
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
VOLUME				
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m ³	cubic meters	36	cubic feet	ft ³
m ³	cubic meters	1.3	cubic yards	yd ³
TEMPERATURE (exact)				
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



* 1 inch = 2.54 centimeters. For other exact conversions and more detailed tables, see NBS Mon. Publ. 250, Guide for Weight and Measure, Price \$2.25. 240 Catalog No. C-13 10 250.

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1.0 INTRODUCTION

Icebergs produced by the glaciers of Greenland's west coast are known to cross Baffin Bay and then proceed southward along the coast of Baffin Island and Labrador. The Labrador current finally carries those few percent which have survived to the southern coast of Labrador, south and east along the margins of the Grand Banks of Newfoundland until they melt in the warmer, sea ice free waters of the northwestern Atlantic. While the average or general route is well known, little has been published about long-term movements of individual icebergs. Information concerning speed, groundings, and trajectory of drift is quite scarce.

In order to answer some of these questions, a program of direct measurements of iceberg movements was started in 1977. This program took advantage of the stability and slow deterioration of large tabular icebergs which were in ice-covered seas and also the development of a satellite-tracking technology. Using ADRAMS (Air-Deployable Random Access Measurement System) ice buoys, which were developed to follow the movements of sea ice north of Alaska, two icebergs were tagged in February 1977 and five more in January 1978.

The majority of icebergs which reach the region near the Grand Banks of Newfoundland are produced by glaciers on the west coast of Greenland north of Disko Bay. These glaciers produce approximately 10^{18} g/year of ice (Bauer, 1955). Kollmeyer (1978) has identified nine major iceberg-producing glaciers on the west coast. They are, from south to north, Jacobshavn, Rinks, Steenstrups, Dietrichsons, Nansens, Kong Oscars, Gade, Heilprin, and Tracy. Of these, Jacobshavn Glacier produces about 7 percent of the west Greenland icebergs and advances at a rate of 23 m/day in the summer (Robe, in press).

No icebergs of any size or significance are produced by glaciers of the Canadian Archipelago except for "ice islands" of the Arctic Ocean which come from the ice shelves of northern Ellesmere Island.

The ADRAMS ice buoy was developed to provide remote tracking of sea ice near the Arctic coast (Brown and Kerut, 1975). The buoy contains a 401.2 MHz transmitter which transmits a digital encoded signal. When this signal is received by the NIMBUS-6 RAMS, a position can be determined by a doppler shift in frequency.

The 80-pound buoy is deployed from an aircraft on its own parachute. The electronics package is housed in a plastic/fiberglass sphere and protected from impact by a bottom-mounted crash pad. This crash pad contains a switch that activates a pyrotechnic line cutter which frees the parachute (Figure 1). The antenna, electronics, and batteries are a single assembly which floats inside the housing sphere. This feature allows the antenna to point upward under all terrain conditions.

The buoys were launched from the rear ramp of a Coast Guard C130. Figures 2 and 3 show the sequence of a launch. The accuracy of the drop depended on the experience of the pilot. Practice drops were conducted using an 80-pound weight similar in size to the ADRAMS buoy attached to a spare parachute.

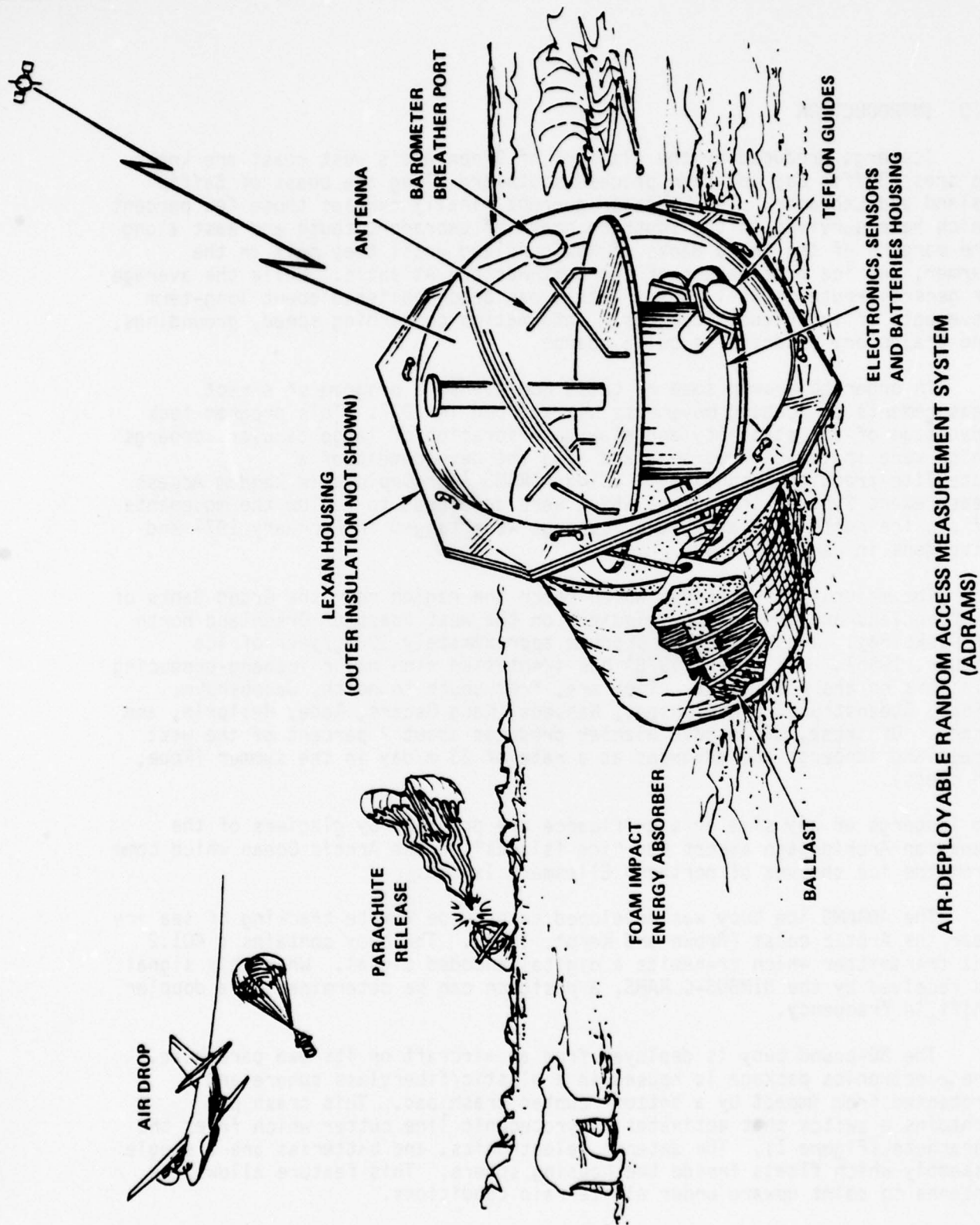


FIGURE 1
ADAMS ICE BUOY SYSTEM



FIGURE 2
ADRAMS READY FOR LAUNCHING



FIGURE 3
ADRAMS DESCENDING TO AN ICEBERG

2.0 DATA PROCESSING

ADRAMS position data received from NASA contains a statistical index as to what confidence can be placed in a given position. While this index was useful for flagging questionable positions, it was by no means foolproof as a guide to either positions which were unquestionably good or those which were unquestionably bad. Additional checks on individual positions were made by comparing drift speeds between observations with average drift speeds and by examining drift direction for 180° shifts. When the obviously bad positions are eliminated, processing continued as follows.

The record of positions versus time is not equally spaced in time and, therefore, less than ideal for analysis purposes. An average of five to six positions were received each day with a high number in any one day of approximately nine positions. Positions during any given day would be from a number of consecutive satellite orbits when the satellite was above the buoy's horizon. These orbits would be followed by a number of orbits in which the satellite was not above the buoy's horizon and consequently the buoy could not be tracked. This produced a pattern of positions which had several spaced closely in time followed by intervals when no positions were received. Adding to this bad positions and system failures, gaps of up to three days could be produced in the record.

The records of latitudes and longitudes were separately converted to equally time-spaced records by using a four-point linear interpolation scheme. Values of latitude and longitude were determined every three hours. Since the orbit time for the NIMBUS was approximately 108 minutes, all data points were used in at least two interpolations.

The interpolated time series of positions with the three-hour time step was then filtered using a low-pass filter with a cut-off of 1.16×10^{-5} Hz or one cycle per day. This effectively removed random errors which appeared in the positions as well as most tidal influences.

In Figure 4 a comparison of the raw quality-controlled data, the interpolated data, and the filtered data for Buoy Number 780156 is presented. The main features of the drift are present in all three data sets.

Drift speeds and directions were computed from the filtered data files.

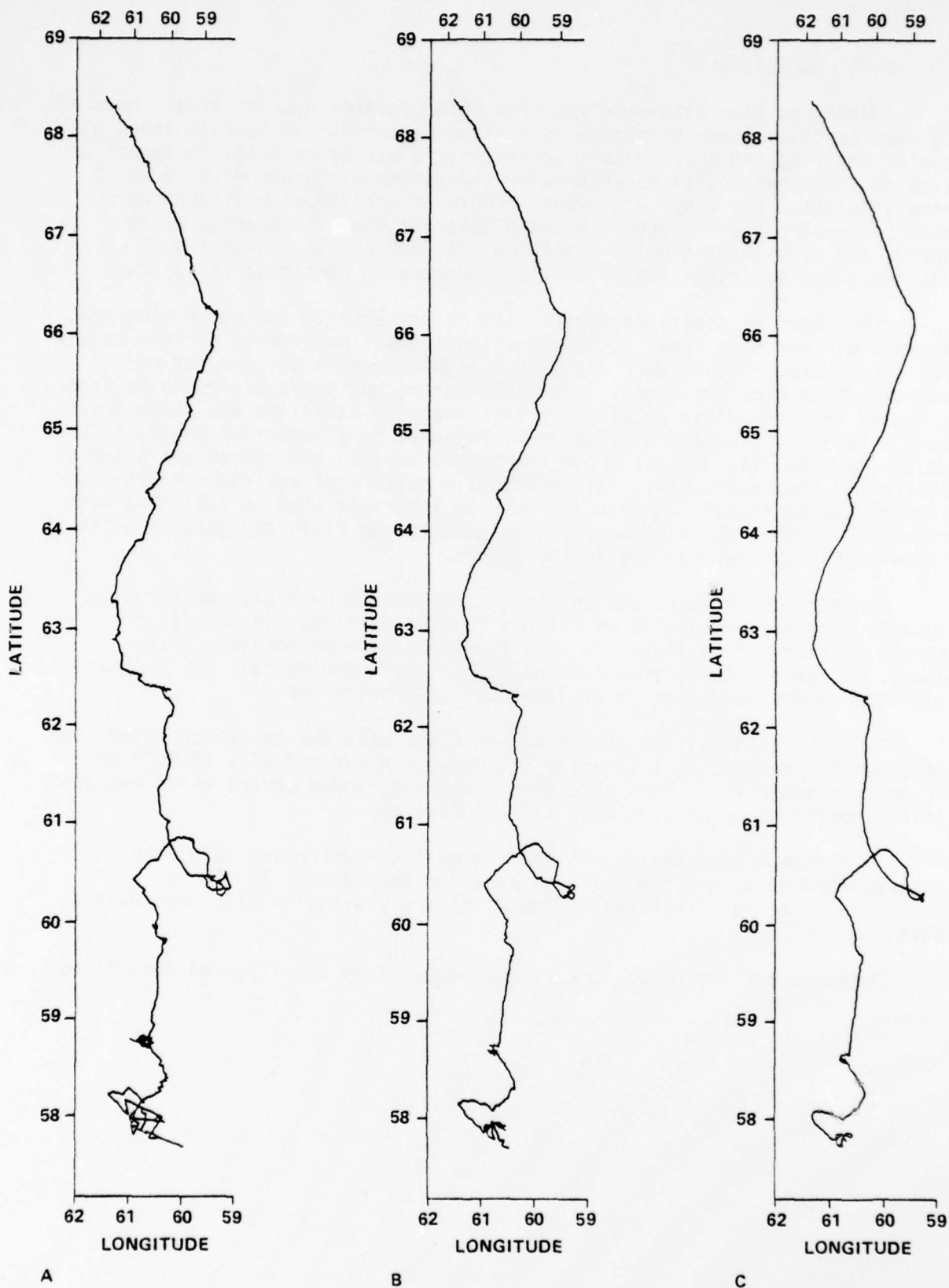


FIGURE 4

A COMPARISON OF THE (a) RAW QUALITY-CONTROLLED DATA, (b) INTERPOLATED DATA, AND (c) FILTERED DATA

3.0 SYSTEM DATA ACCURACY

The NIMBUS-6 RAMS has an advertised system accuracy of ± 5 km for positioning. By a chance occurrence, two ADRAMS were deployed on the same iceberg, one in January 1978 and one in February 1978. Both ice buoys transmitted together for a total of 144 days. Analysis of the processed data established that the buoys had a separation of 310 to 320 meters and that the uncertainty in position was ± 3.52 km with 95 percent confidence.

4.0 1977 DRIFTS

Buoy Platform Number 770156 was dropped at 1645Z, 25 February 1977, on the iceberg shown in Figure 5. The position of the iceberg at the time of the drop was 69-16.6N and 56-00W. The drift (Figure 6) track was first toward the south crossing over a shoal which was 110 to 120 meters deep. After crossing the channel (460 meters deep) coming out of Disko Bay, the iceberg ran aground on a shoal on the southern side of the channel. This area shoals quite rapidly and the iceberg grounded in 90 to 100 meters of water. The iceberg was aground throughout much of the tracking period (Figure 7). Twice it moved northward into the channel. Once for a 17-day period, Julian date 90 to 107, the iceberg drifted into the channel then returned to the shoal on the southern side of the channel. On Julian date 150, the iceberg drifted northward and grounded in 90 meters of water north of the channel. After four and a half days aground the iceberg drifted eastward into the mouth of Disko Bay where contact was lost. The iceberg was aground during 38 percent of time it was tracked. Twelve-hour averages of speed, when the iceberg was not grounded, had a modal value of less than 0.10 m/s with the maximum drift speed not exceeding 0.40 m/s (Figure 8).

Buoy Platform Number 770160 was dropped at 1800Z, 25 February 1977. The position of the iceberg at the time of the drop was 68-02N, 61-37W. The drift track (Figure 9) follows the contour of the bathymetry from Davis Strait (66°N) to south of 50°N in 122 days. During the entire drift the iceberg never grounded (Figure 7). Evidence of the control of bathymetry on the current can be seen by the westward movement toward Hudson Strait near 61-18N on Julian dates 120 to 130 and again when the iceberg moves westward toward the indentation of the Continental Shelf near 56-18N (Cartwright Saddle) on Julian day 148. The iceberg reached its extreme southerly point on Julian day 194 at 49-09N, 49-11W. From this point, it drifted northeasterly. Changes in drift speeds and a decrease in buoy internal temperature fluctuations indicated that the buoy fell off the iceberg on Julian day 226 near 51-70N, 44-30W. The buoy continued to drift toward the northeast and transmitted until Julian day 235. A summary of twelve-hour averages of drift speed is presented in Figure 10. From the start of the drift at 68-02N until the iceberg reached 65°N, the distribution of speed was very flat with no values exceeding 0.40 m/s. The drift in the latitude interval including 60°N to 65°N had a definite modal speed value falling between 0.10 and 0.20 m/s. The high value did not exceed 0.50 m/s. The highest speeds and the highest modal drift speed for this iceberg occurred in the interval including 55°N to 60°N. No twelve-hour averages were less than 0.10 m/s and the high value was between 0.70 and 0.80 m/s. The modal values were also quite high falling in the interval 0.30 and 0.40 m/s. The drift in the latitudes 50°N and 55°N had a broad modal peak occurring between 0.20 and 0.40 m/s. Speeds were still quite high with minimum values in excess of 0.10 m/s and maximum speeds as high as 0.70 m/s. In the latitude range 49°N to 50°N, the iceberg slowed considerably having a maximum speed of less than 0.40 m/s and a modal speed between 0.10 m/s and 0.20 m/s. The final segment of drift fell in the latitude range of 50°N to 52°N, when the drift was strongly toward the northeast into the Labrador Sea. Before the buoy fell off the iceberg, the speed distribution was quite flat from 0.00 to 0.50 m/s. After the buoy was in the water, speeds as high as 0.92 m/s were observed.

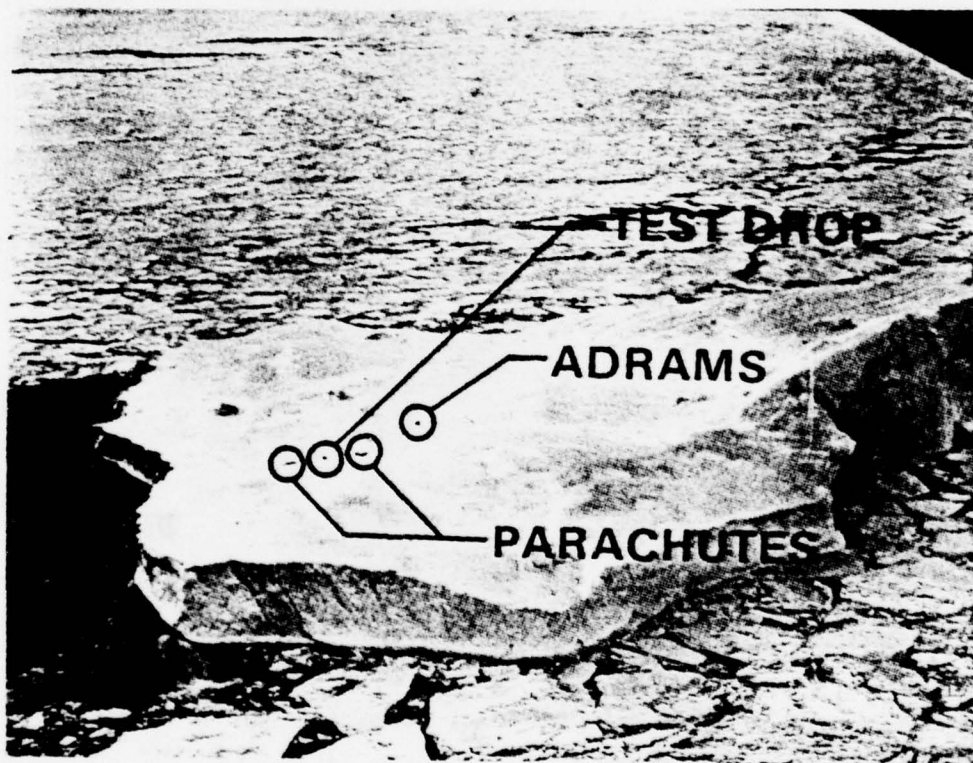


FIGURE 5

ICEBERG TAGGED WITH BUOY NUMBER 770156

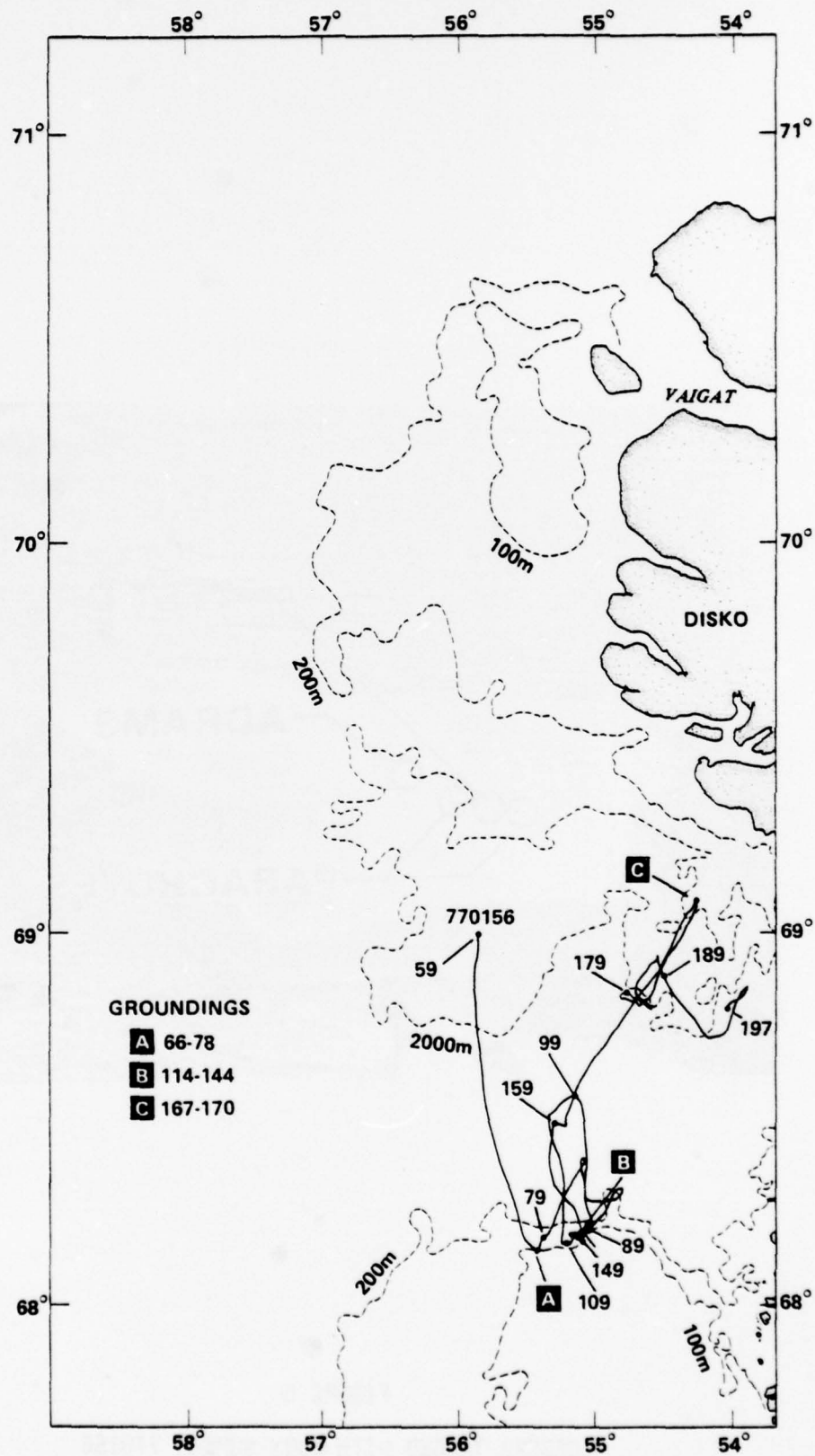
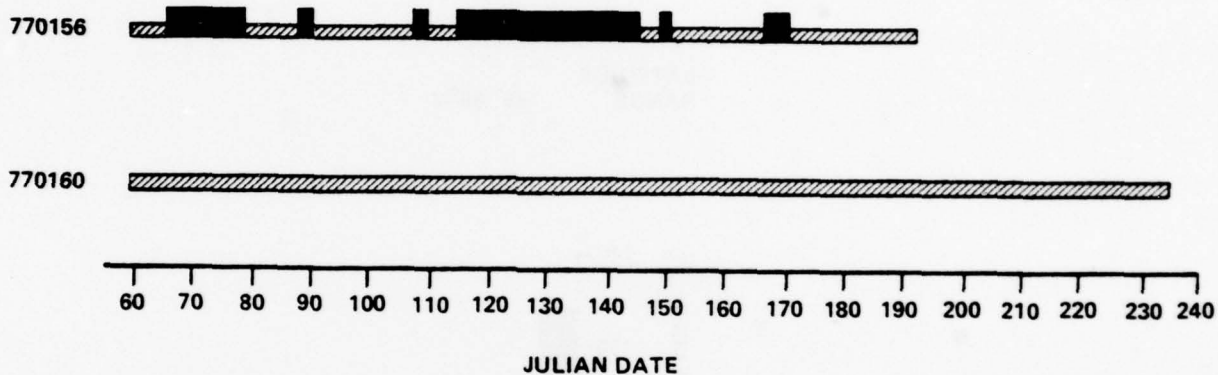


FIGURE 6

DRIFT TRACK OF BUOY NUMBER 770156



LEGEND

- FIRMLY GROUNDED
- INTERMITTENTLY GROUNDED
- ▨ DRIFTING

DRIFT AND GROUNDINGS OF ICEBERGS TRACKED DURING 1977

FIGURE 7

DRIFT AND GROUNDINGS OF ICEBERGS TRACKED DURING 1977

PLATFORM NO.
770156

LATITUDE
RANGE 68°-69°N

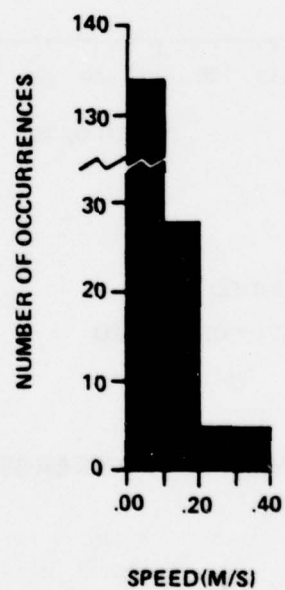


FIGURE 8
DISTRIBUTION OF SPEED FOR BUOY NUMBER 770156

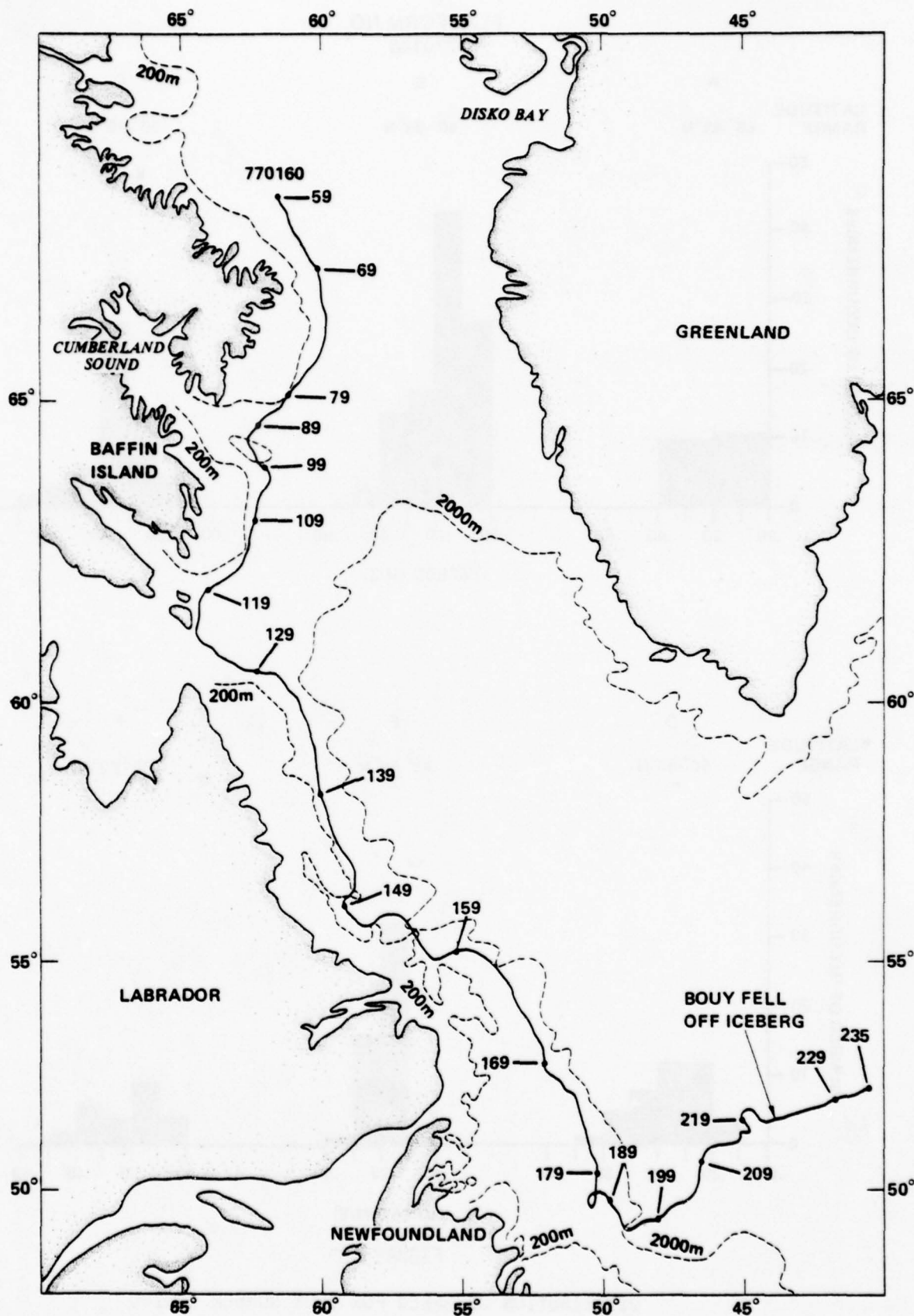


FIGURE 9

DRIFT TRACK OF BUOY NUMBER 770160

PLATFORM NO.
770160

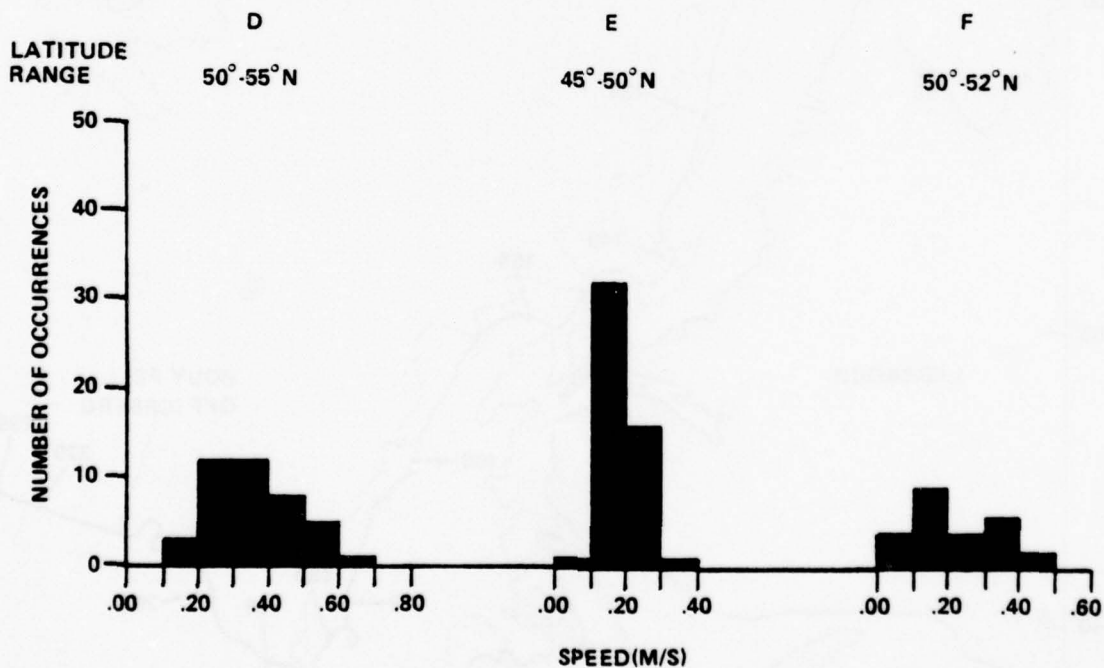
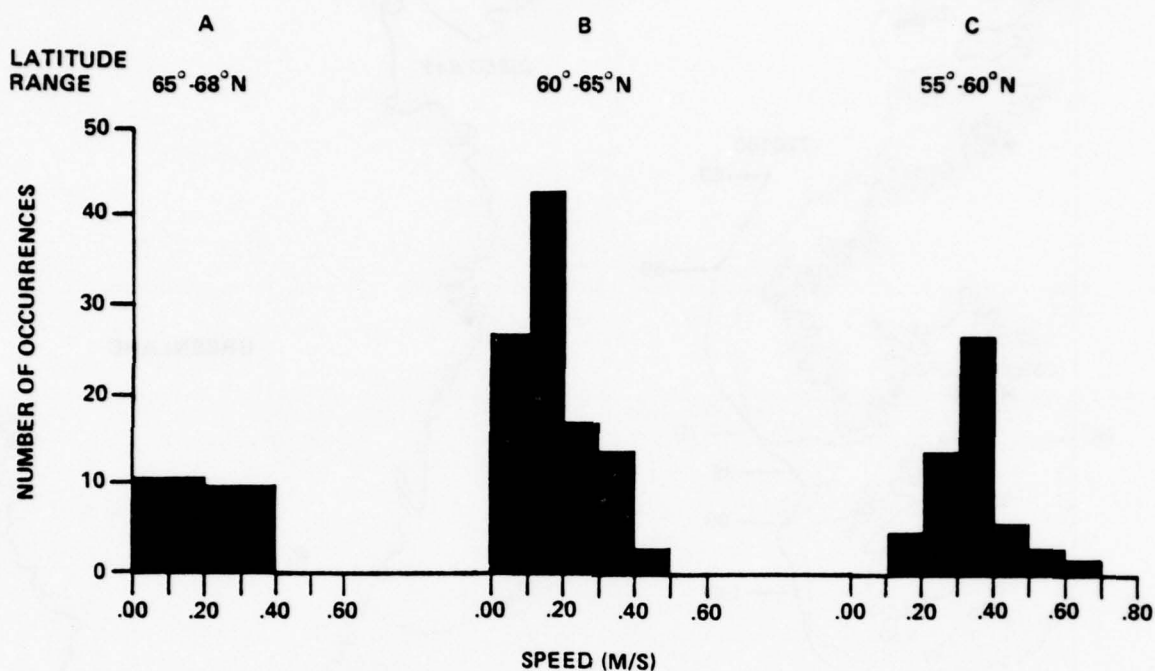


FIGURE 10

DISTRIBUTION OF SPEED FOR BUOY NUMBER 770160

5.0 1978 DRIFTS

Buoy Platform Number 780050 was dropped at 1630Z, 29 January 1978, on an iceberg at 68-32.4N, 62-27.7W (Figure 11). The iceberg was estimated to have a length in excess of 300 meters and a height of nearly 70 meters. The drift (Figure 12) generally followed the bathymetry and included two grounding episodes which occupied 53 percent of the total tracking period of 174 days (Figure 13). The first grounding occurred in 140 to 150 meters of water on a shoal area off the mouth of Cumberland Sound, Baffin Island. The iceberg continued to move slightly during the grounding period which lasted from Julian date 68 to Julian day 154. On Julian day 202, the iceberg again grounded on the coastal shoal at 63-10N where contact was lost. The twelve-hour averages of drift speed in the latitude range 65°N to 68°N have a fairly flat distribution up to 0.40 m/s with a modal drift speed of between 0.10 and 0.20 m/s (Figure 14). In the latitudes 63°N to 65°N, the speed distribution was strongly skewed toward the lower speeds. The modal value was less than 0.10 m/s with a maximum speed of under 0.40 m/s.

Buoy Platform Number 780066 was dropped at 1300Z, 6 February 1978, on an iceberg at 62-58N, 62-50W (Figure 15). The iceberg was estimated to have a length in excess of 300 meters and a height of 30 to 40 meters. The drift of 780066 began at nearly the same location that the drift of 780050 ended (Figure 16). The entire drift of this iceberg was in water shallower than 220 meters. The iceberg followed the bathymetry closely and was grounded fully 88 percent of the time tracked (Figure 13). The longest period of drift for this iceberg was approximately thirteen days. When drifting, this iceberg had very low speed with modal values of less than 0.10 m/s and maximum speed which did not exceed 0.30 m/s (Figure 17).

Buoy Platform Number 780156 was dropped at 1610Z, 29 January 1978, on an iceberg at 68-30.1N, 62-02.8W (Figure 18). The iceberg had a length estimated at 350 to 400 meters and an estimated height of 75 meters. 780156 was dropped on an iceberg floating in nearly 1800 meters of water. This iceberg's track followed the coast-wise current in a manner similar to other icebergs in this study as far south as 64°N or just south of Cumberland Sound (Figure 19). From this point, the track was much more southerly than most icebergs in this study, showing no movement westward toward Hudson Strait. From Julian day 85 to 102, the iceberg moved in a figure eight pattern just north of 60°N east of 60°W. This movement took place in water over 1800 meters deep just off the Continental Shelf. The next iceberg to be discussed, 781344, was just inshore over the shelf during this period (Figure 20) and shows no such movement. Likely the iceberg passed eastward through the southward flowing current with flows along the shelf and was caught in an eddy. After completing the figure eight, 780156 moved southwesterly onto the shelf where a southerly drift was resumed. A grounding occurred at 58-40N in approximately 200 meters which occupied 34 percent of the total drift period (Figure 13). The loop to the west just north of 58°N takes the iceberg into water shallower than 180 meters which indicates a 10% draught reduction. An analysis of temperatures within the

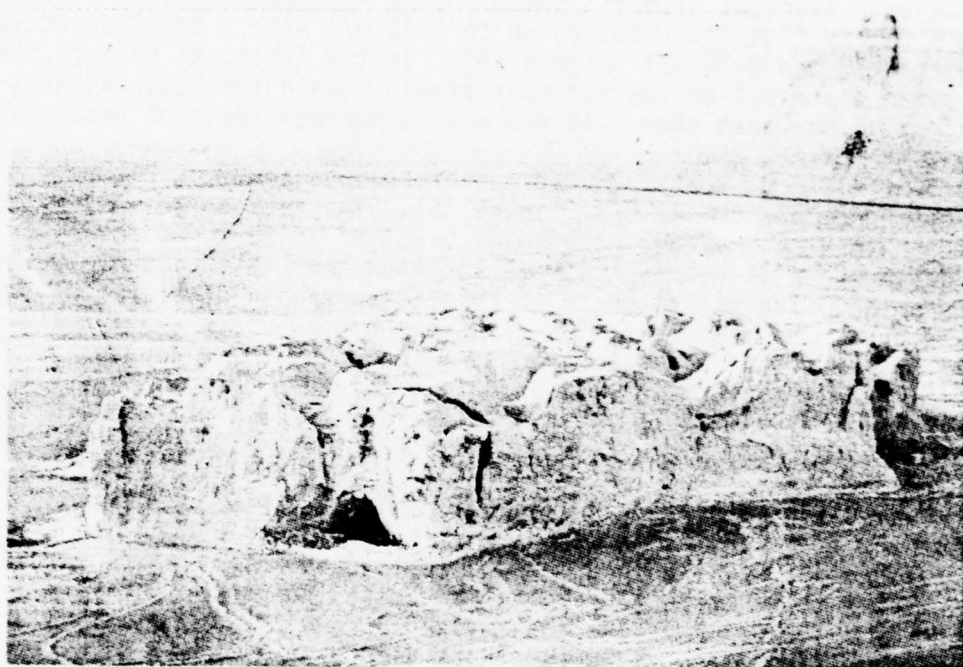


FIGURE 11
ICEBERG TAGGED WITH BUOY NUMBER 780050

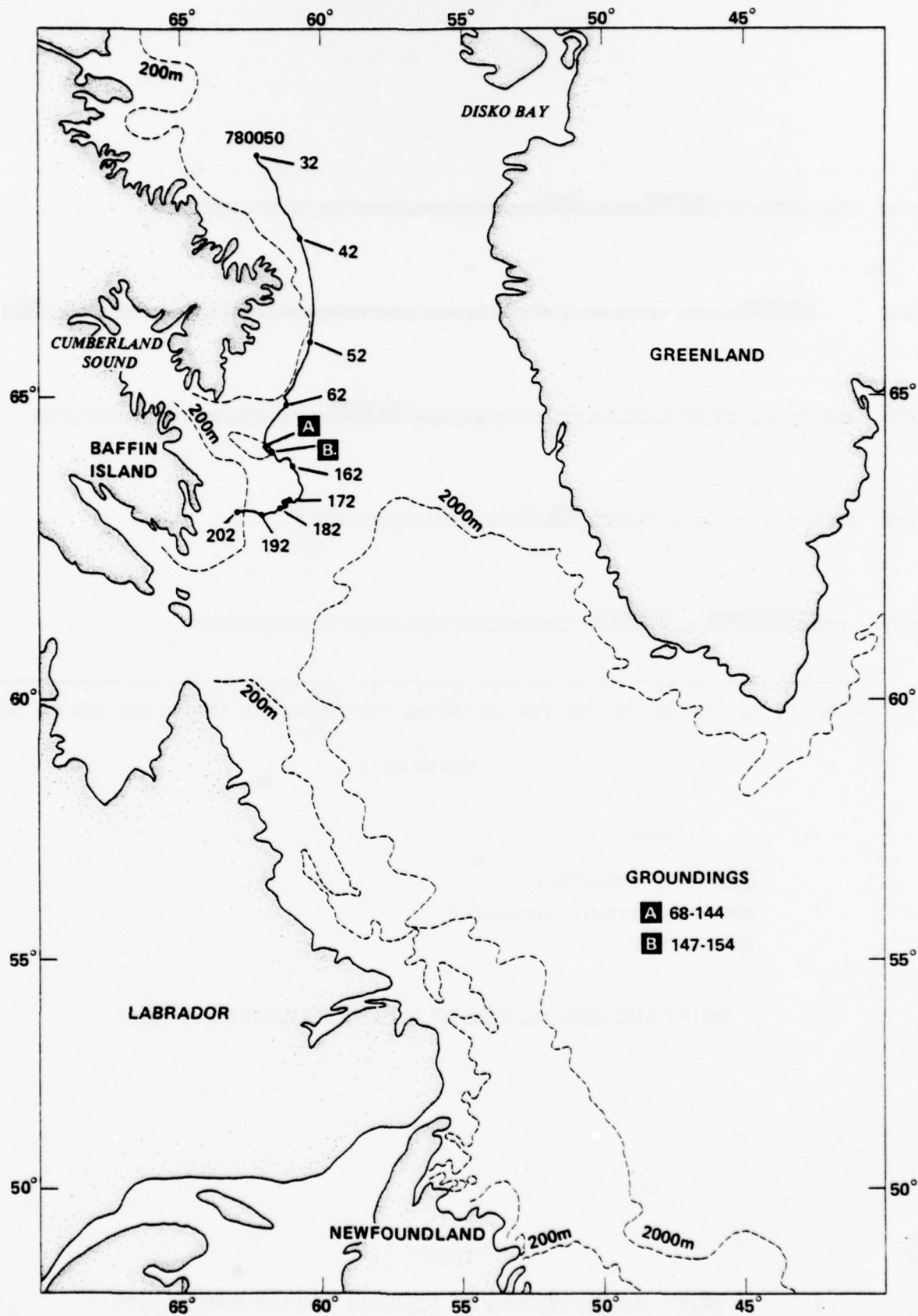
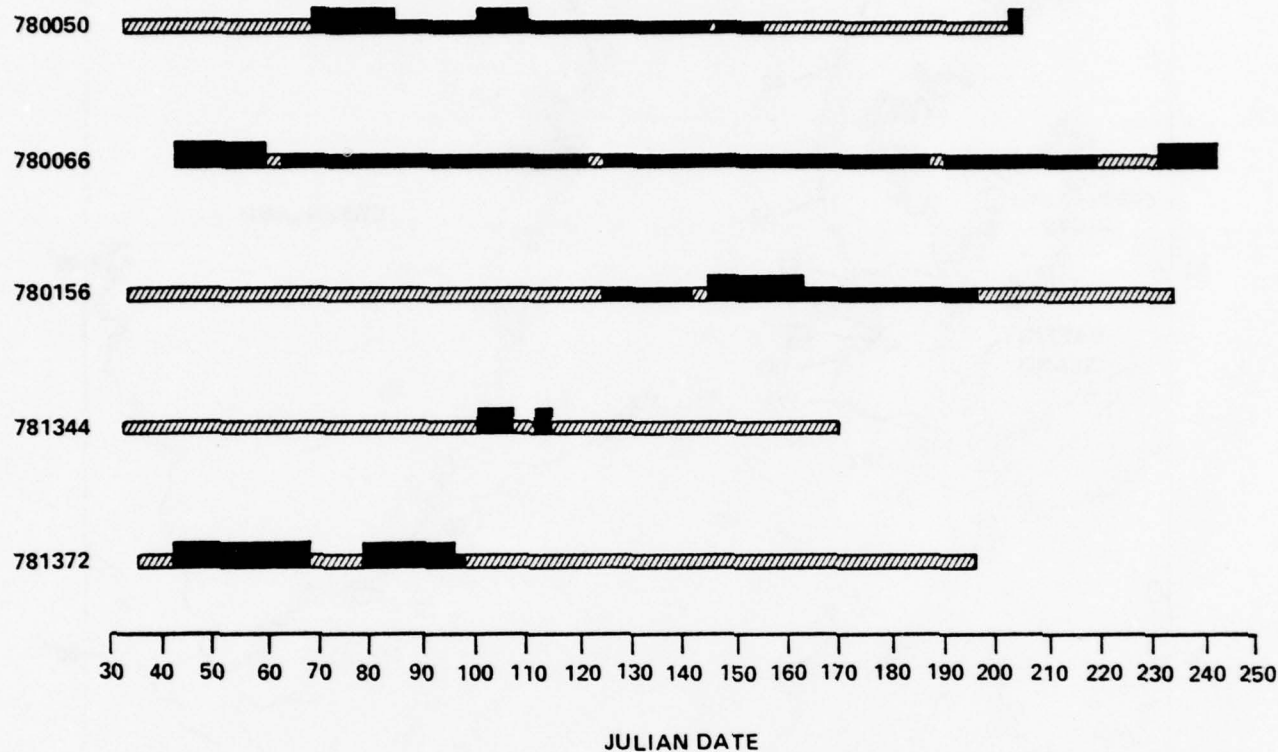


FIGURE 12

DRIFT TRACK OF BUOY NUMBER 780050



LEGEND

- FIRMLY GROUNDED
- INTERMITTENTLY GROUNDED
- DRIFTING

DRIFT AND GROUNDINGS OF ICEBERGS TRACKED IN 1978

FIGURE 13

DRIFT AND GROUNDINGS OF ICEBERGS TRACKED DURING 1978

PLATFORM NO.
780050

	A	B
LATITUDE RANGE	65°-68°N	63°-65°N

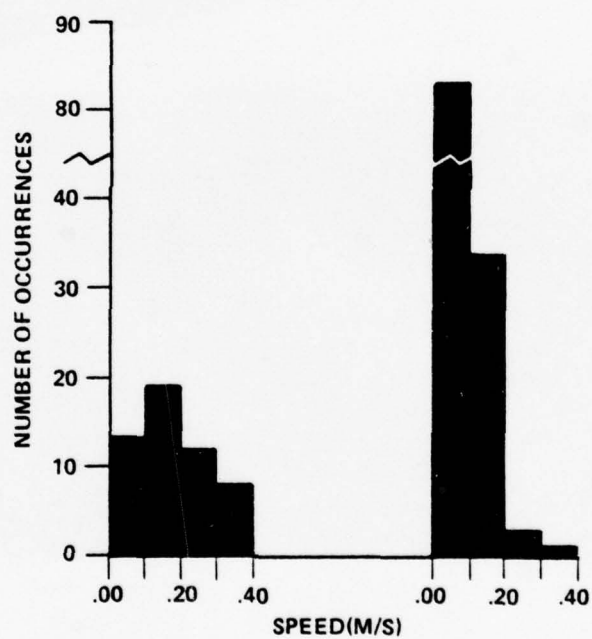


FIGURE 14
DISTRIBUTION OF SPEED FOR BUOY NUMBER 780050

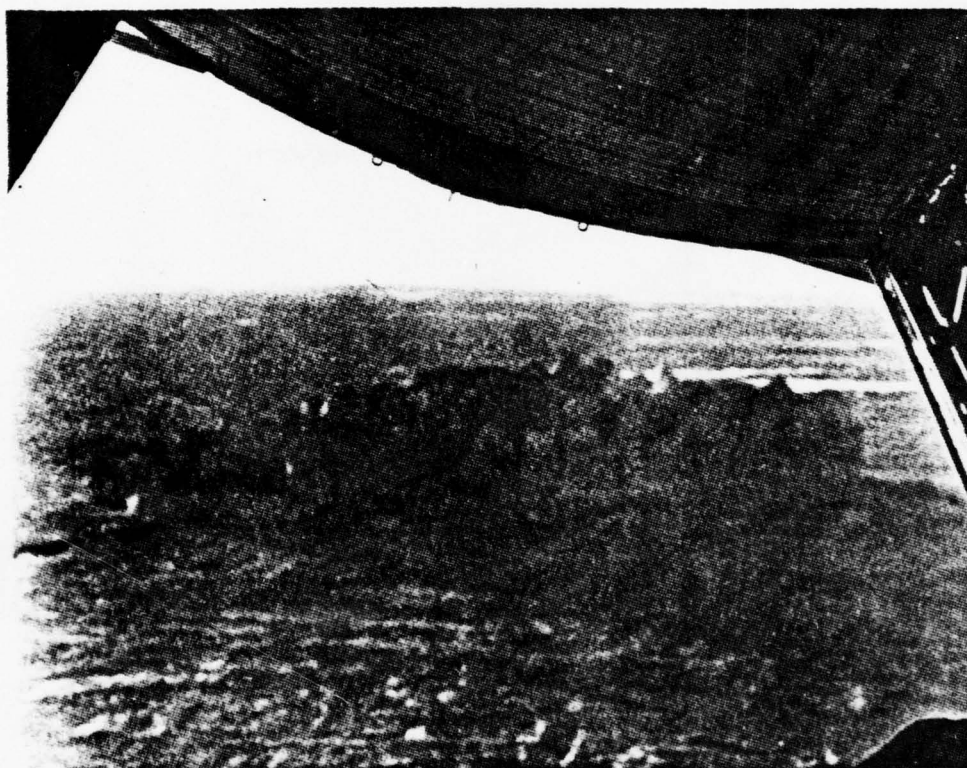


FIGURE 15
ICEBERG TAGGED WITH BUOY NUMBER 78066

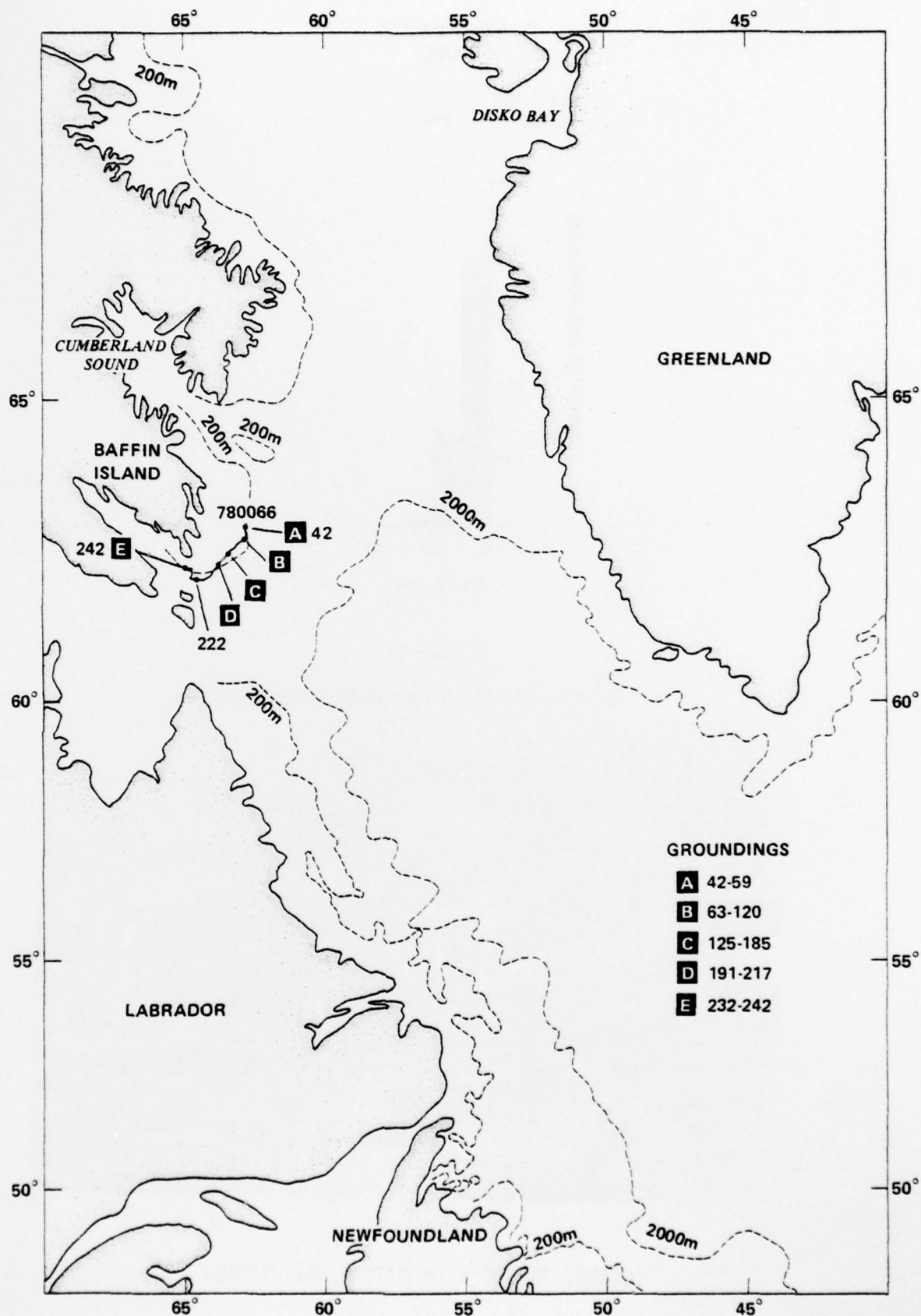


FIGURE 16

DRIFT TRACK OF BUOY NUMBER 780066

PLATFORM NO.
780066

LATITUDE
RANGE 62° N

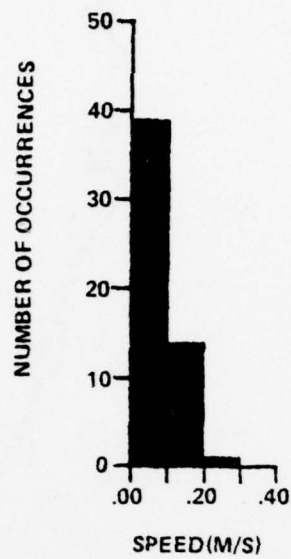


FIGURE 17

DISTRIBUTION OF SPEED FOR BUOY NUMBER 780066



FIGURE 18

ICEBERG TAGGED WITH BUOY NUMBER 780156

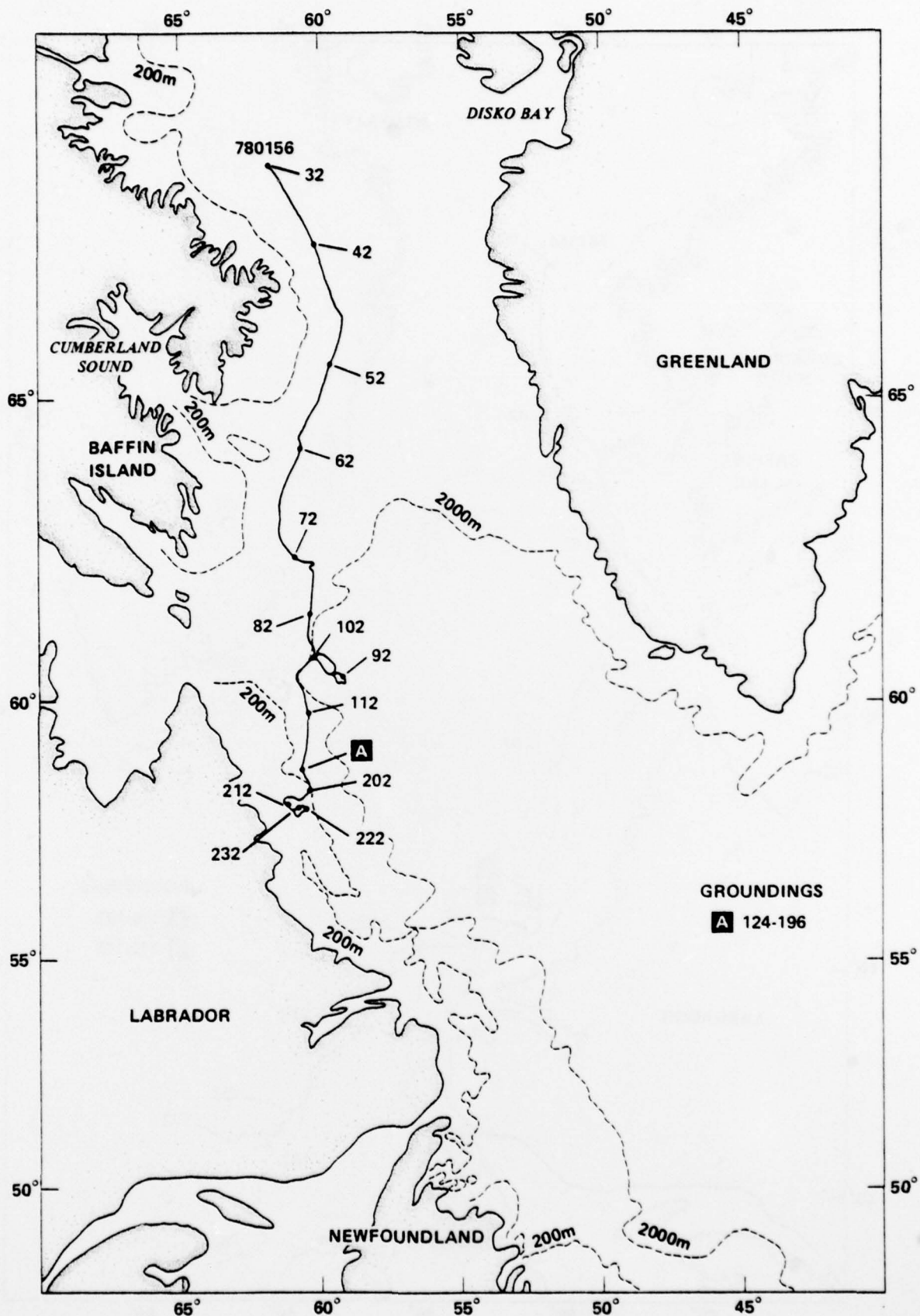


FIGURE 19

DRIFT TRACK OF BUOY NUMBER 780156

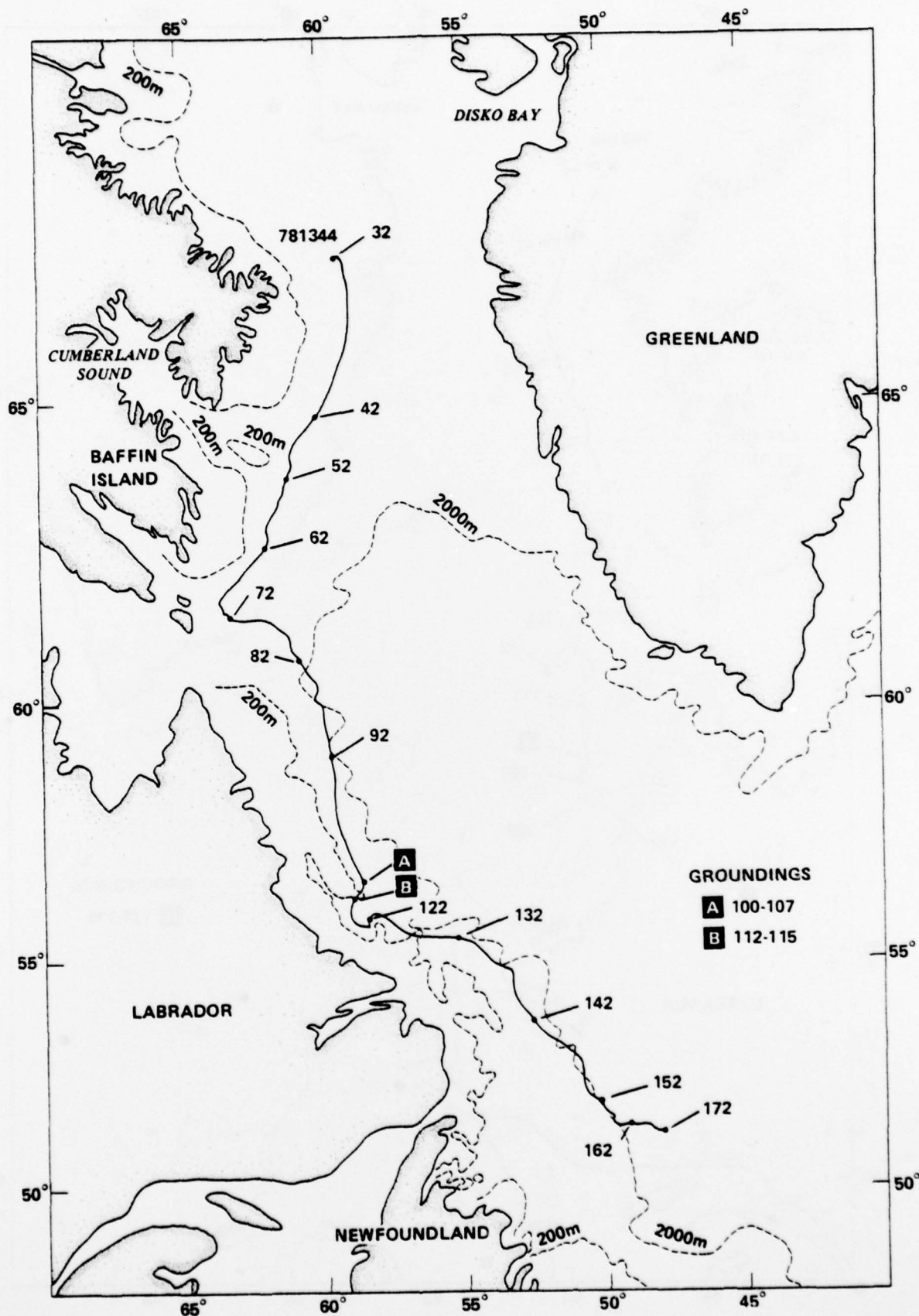


FIGURE 20

DRIFT TRACK OF BUOY NUMBER 781344

ice buoy indicate that the buoy probably fell from the iceberg on Julian day 217. North of 65°N, the speed distribution has a peak between 0.10 and 0.20 m/s but was fairly flat up to 0.40 m/s (Figure 21). Maximum speeds did not exceed 0.50 m/s. In the latitude range 60°N to 65°N, the speed distribution had a strong peak between 0.10 and 0.20 m/s. Maximum values did not exceed 0.50 m/s. The speed distribution in this latitude range did not appear to be altered in character by the figure eight movement mentioned earlier. South of 60°N, the movement of the iceberg when not grounded slowed considerably with few speeds exceeding 0.20 m/s and a strong modal speed between 0.00 and 0.10 m/s. No speeds were higher than 0.50 m/s.

Buoy Platform Number 781344 was dropped at 1725Z, 29 January 1978, on the iceberg shown in Figure 22. This iceberg was approximately 600 meters long and 80 meters high. The position of the iceberg at the time of the drop was 67-23.8N, 59-26.2W. The drift track followed the Baffin Island and Labrador current from north of 67°N to nearly 51°N (Figure 20). Two open loops to the west occurred. The first near the entrance to Hudson Strait and the second near a pronounced shoreward indentation of the 200 meter bathymetric contour near 56°N, 59°W. This area also was the location of the iceberg grounding for 8 percent of its total tracking period (Figure 13). The draught of this iceberg was approximately 180 meters. The distribution of speeds for this iceberg north of 65°N was flat from 0.00 to 0.70 m/s with no prominent peaks (Figure 23). Between 60°N and 65°N, there was a strong peak in the interval 0.10 to 0.20 m/s. In the latitude interval 55°N to 60°N a broad peak of speed was between 0.10 and 0.40 m/s with a maximum speed of less than 0.60 m/s. South of 55°N, the speed distribution was skewed slightly toward the low end with the modal values between 0.20 and 0.30 m/s. The maximum speed was under 0.50 m/s.

Buoy Platform Number 781372 was dropped at 1432Z, 1 February 1978, on the iceberg shown in Figure 24. The iceberg was located at 70-51.3N, 55-20.3W at the time the ADRAMS was deployed. The length was estimated at 250 meters while the height was 45 meters with a 75 meter peak. This ADRAMS was recovered by a helicopter from the CGC WESTWIND at 2000Z, 17 July 1978, at 71-24N, 58-18W (Figure 25). The size was measured as 209 meters wide, 291 meters long, and 49 meters high. These size measurements are more reliable than the aircraft estimates made during deployment. The iceberg appeared to have changed little in size, but had lost the 75 meter peak (Figure 26). Groundings on a shoal west of Disko Island indicate a draught of approximately 130 meters although soundings in this area are extremely uncertain. Two groundings occurred during this time period on the shoal area west of Disko Island which were 25 percent of the tracking period (Figure 13). The drift track (Figure 27) carried the iceberg in an erratic but generally southeasterly direction passing north of Hare Island and into the Viagat Channel between Greenland and Disko Island. The iceberg came out of the Viagat on Julian day 135 and completed a loop to the south between Julian day 137 and 164. Movement from Julian day 168 on was strongly westward until the buoy was picked up by the CGC WESTWIND. All of the twelve-hour averages of speed (Figure 28) fell below 0.20 m/s. Over two-thirds were below 0.10 m/s.

PLATFORM NO.
780156

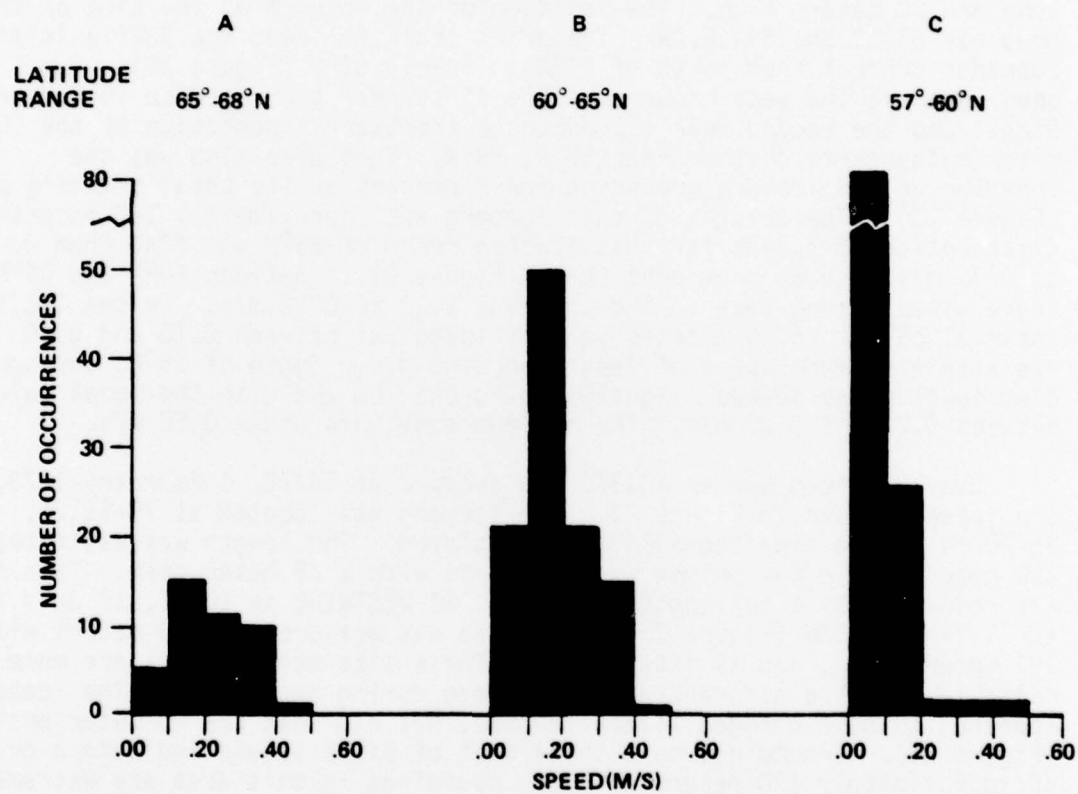


FIGURE 21
DISTRIBUTION OF SPEED FOR BUOY NUMBER 780156

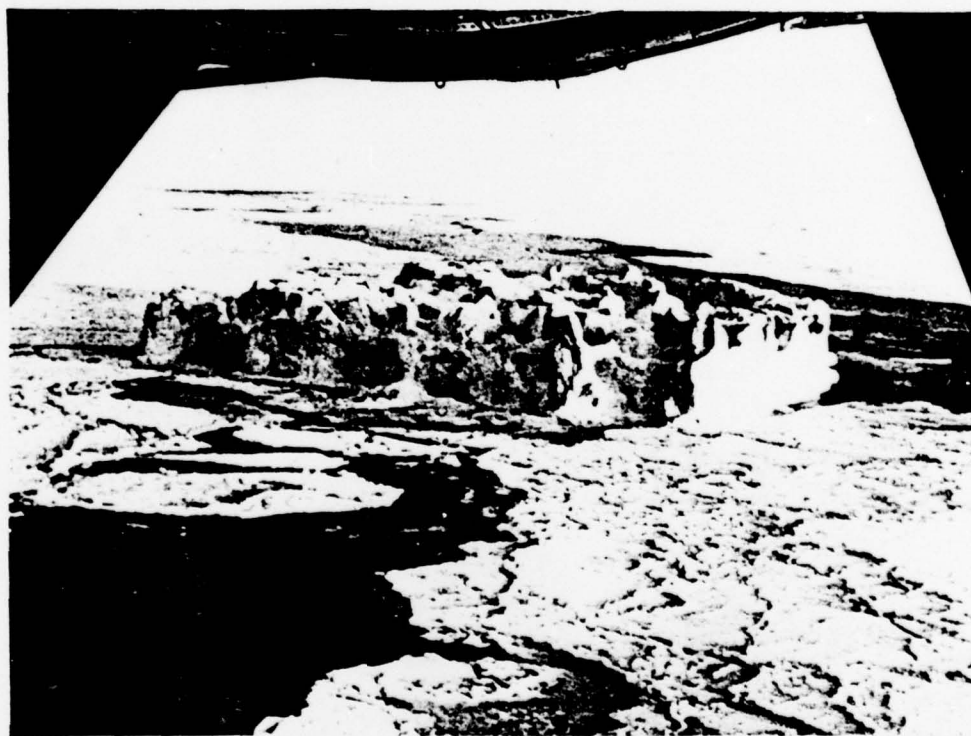


FIGURE 22

ICEBERG TAGGED WITH BUOY NUMBER 781344

PLATFORM NO.
781344

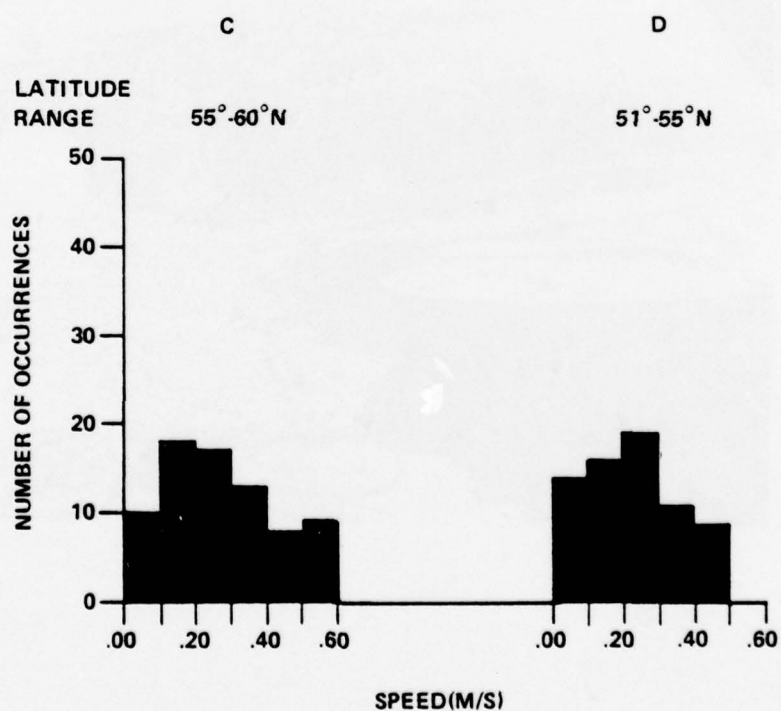
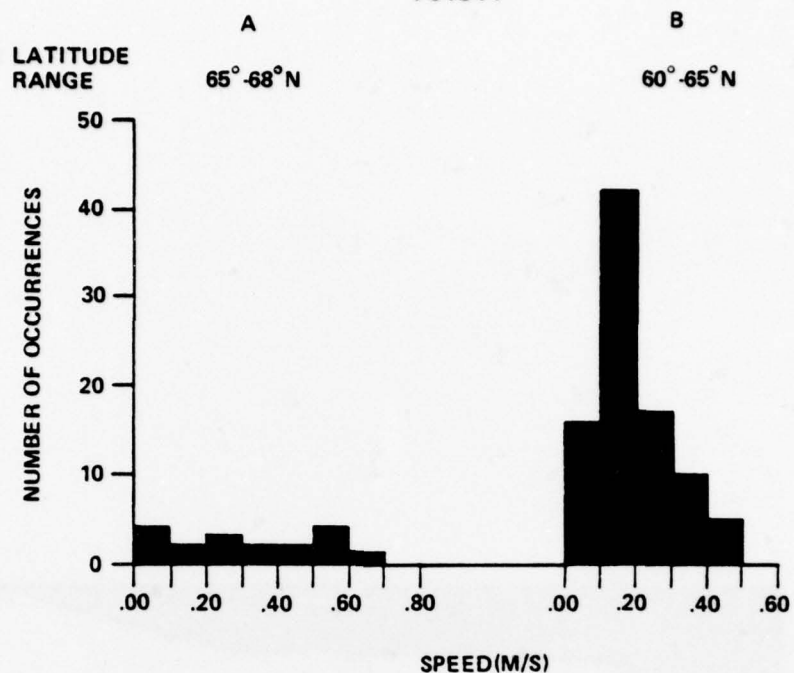


FIGURE 23

DISTRIBUTION OF SPEED FOR BUOY NUMBER 781344

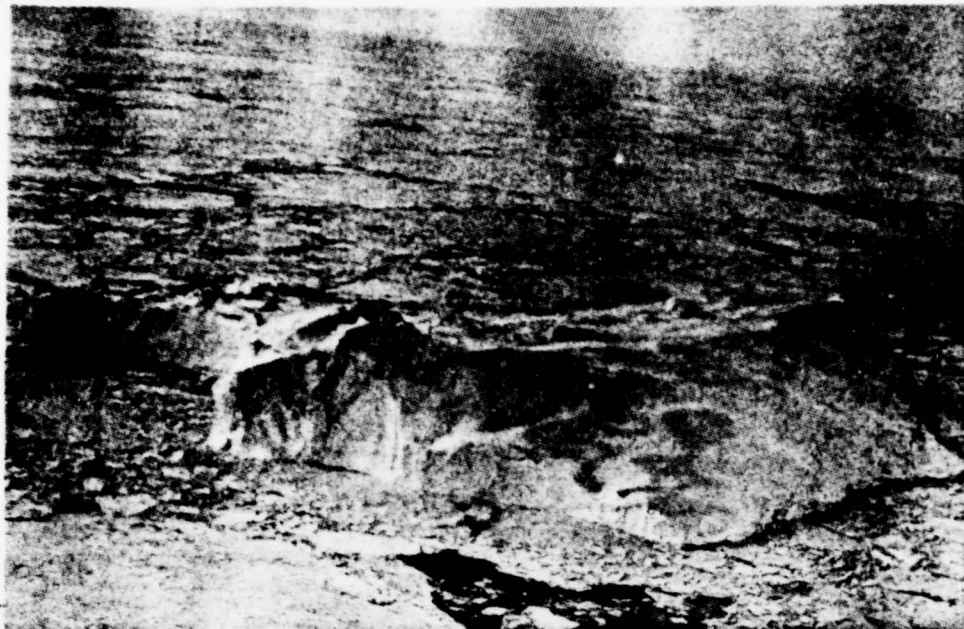


FIGURE 24

ICEBERG TAGGED WITH BUOY NUMBER 781372 - 1 FEBRUARY 1978

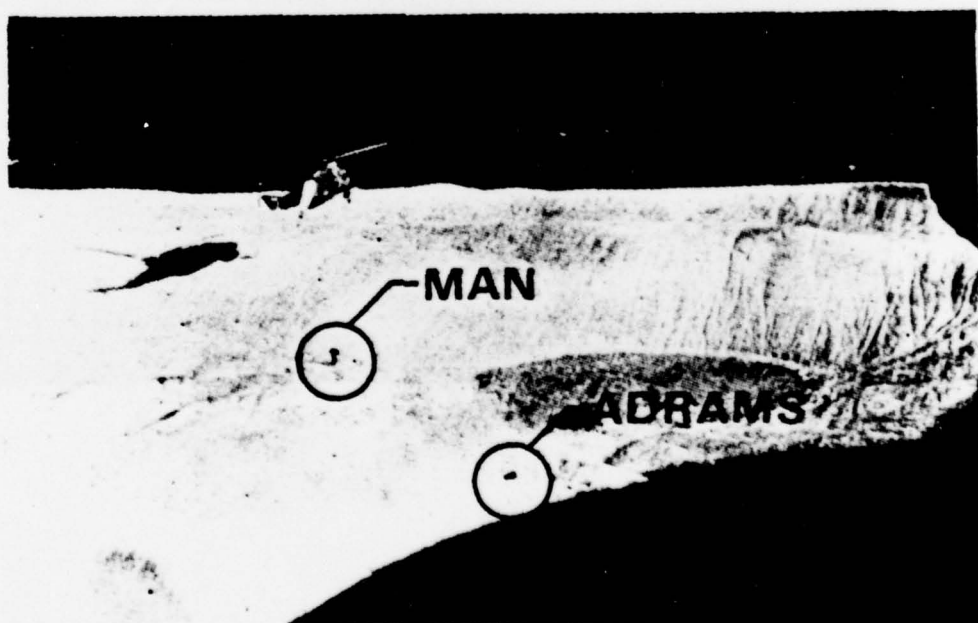


FIGURE 25

RECOVERY OF BUOY NUMBER 781372 BY A HH52 HELICOPTER FROM
THE USCGC WEST WIND

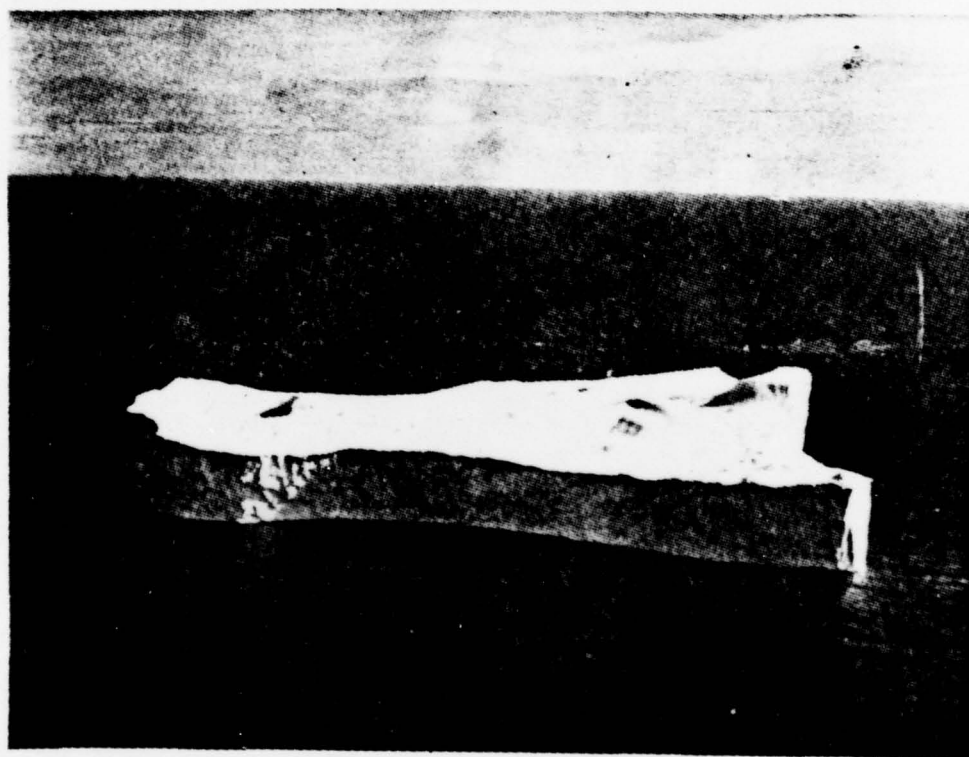


FIGURE 26

ICEBERG TAGGED WITH BUOY NUMBER 781372 - 17 JULY 1978

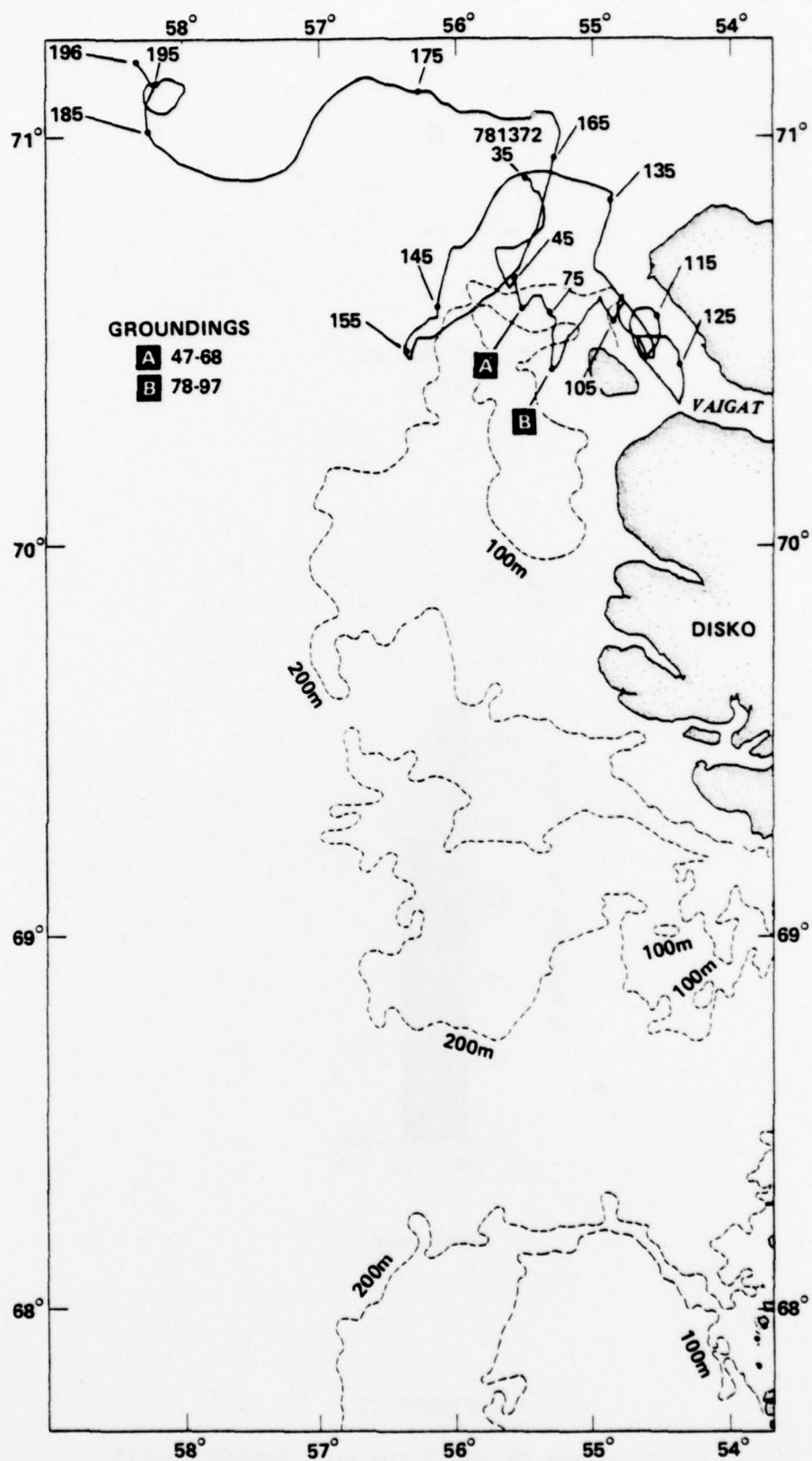


FIGURE 27

DRIFT TRACK OF BUOY NUMBER 781372

PLATFORM NO.
781372

LATITUDE
RANGE 70°-71°N

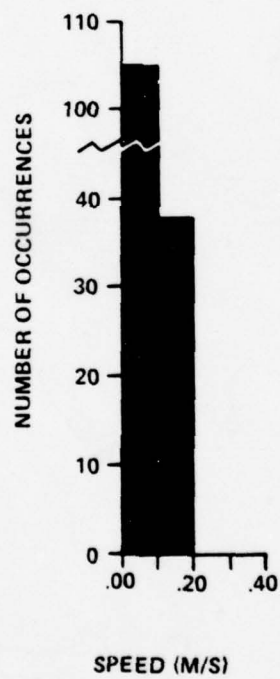


FIGURE 28
DISTRIBUTION OF SPEED FOR BUOY NUMBER 781372

6.0 CONCLUSIONS

The icebergs near Disko Island, Greenland, near the very productive Jacobshavn Glacier do not appear to be influenced by any well-defined current system. Speeds were seldom greater than 0.20 m/s and the drift paths were erratic. Both icebergs tracked in this area, 781372 and 770156, drifted into the channels north and south of Disko Island, the Viagat and Disko Bay respectively. Tracking of 770156 was then lost while 781372 drifted back out of the Viagat. Icebergs seen in these coastal channels may as likely be from the open sea as from local glaciers.

Icebergs on the Baffin Island side of Baffin Bay follow the prevailing currents southward (Figure 29). Groundings occur frequently occupying nearly 40 percent of the observed time. Speed distributions varied little from region to region along the coast except that the speeds along the Labrador coast were somewhat higher than elsewhere. Speeds between 55°N and 60°N ran as high as 0.80 m/s.

From this data, an estimate of the time necessary for an average iceberg to travel the 1100 nautical miles from Cape Dyer, Baffin Island to 50°N on the northern margin of the Grand Banks of Newfoundland was approximately 190 days.

Although groundings were quite common, no icebergs were observed drifting permanently offshore into the Labrador Sea before they had reached the northern edge of the Grand Banks.

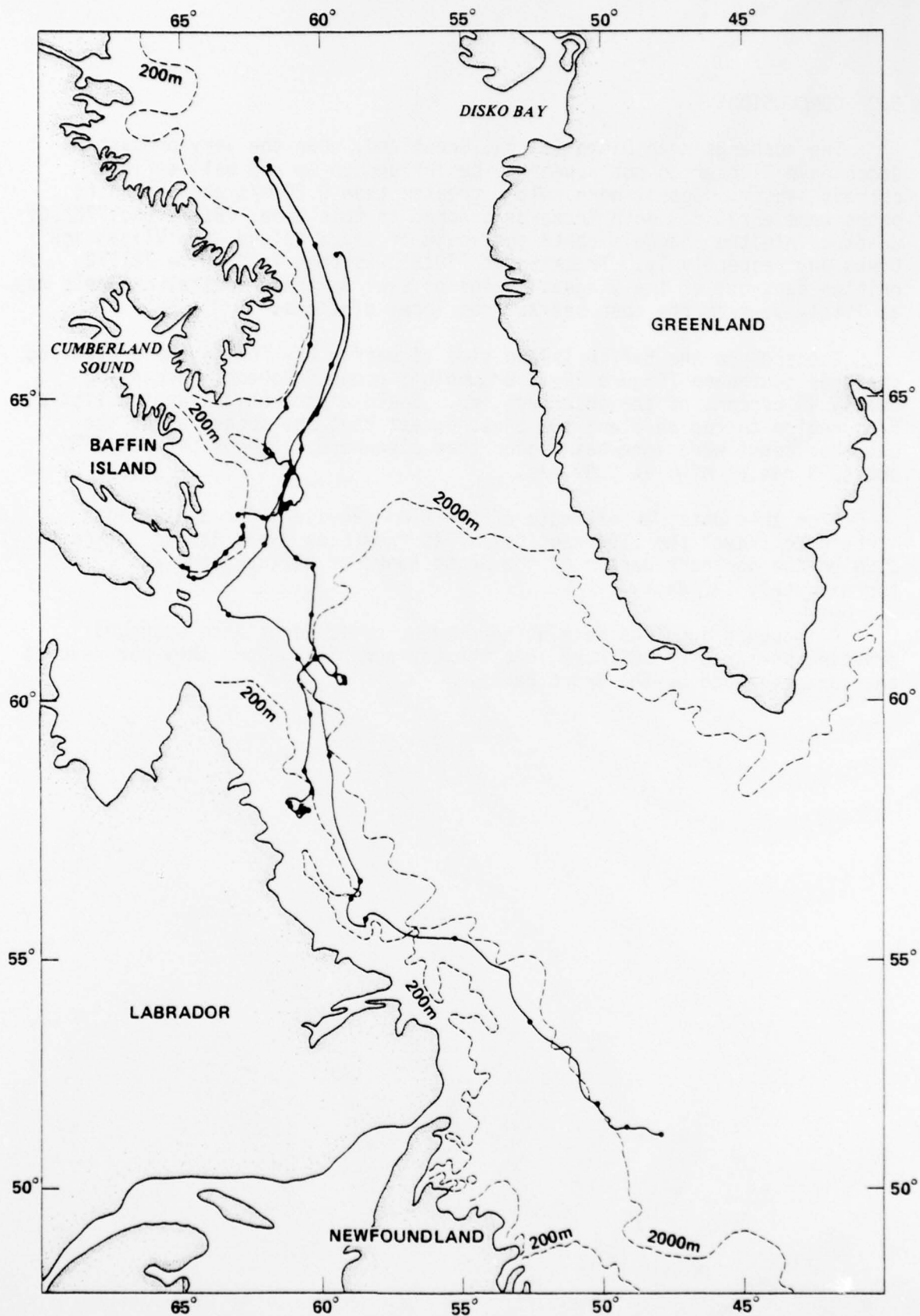


FIGURE 29

COMPOSITE OF 1978 DRIFT TRACKS ALONG THE CANADIAN COAST

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